Towards a Global Census of Rainfall Microphysics

S. Joseph Munchak, Code 612, NASA GSFC and University of Maryland/ESSIC,

C. Kummerow and G. Elsaesser, Department of Atmospheric Science, Colorado State University

An experimental algorithm to retrieve rainfall rates and median raindrop size (D_0) was applied to data from the Precipitation Radar (PR) and Microwave Imager (TMI) on NASA's Tropical Rainfall Measuring Mission Satellite. The combination of instruments allows a more accurate retrieval of these two parameters than is possible with either instrument alone. This knowledge is important for improving radar-based rainfall estimates (a 25% change in D_0 is equivalent to a 90% change in rain rate)

- Global maps of D_0 reveal distinct regional patterns, with larger drops in areas of deep convection in the tropics (western Pacific and Caribbean/Central America), and towards the mid-latitudes (Figure 1 top).
- A significant fraction (45%) of the regional variability can be predicted by the background environment, mesoscale organization, and storm vertical structure (Figure 1 bottom), suggesting that these all influence rain microphysical processes.
- A much more detailed examination of these relationships will be possible with the dual-frequency radar and high-resolution radiometer on NASA's upcoming Global Precipitation Measurement (GPM) satellite (Figure 2).

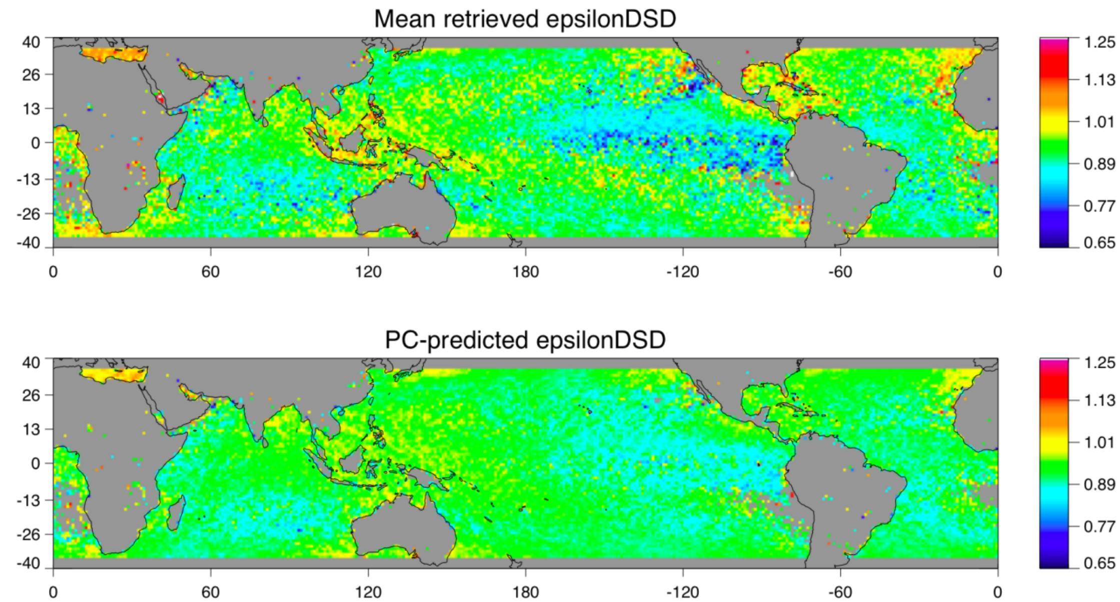


Figure 1: Top panel: Mean value of reflectivity-normalized median raindrop size (a value of 1 represents the global mean). Bottom panel: Mean reflectivity-normalized drop size predicted by a combination of environmental, mesoscale organization, and storm vertical structure parameters.

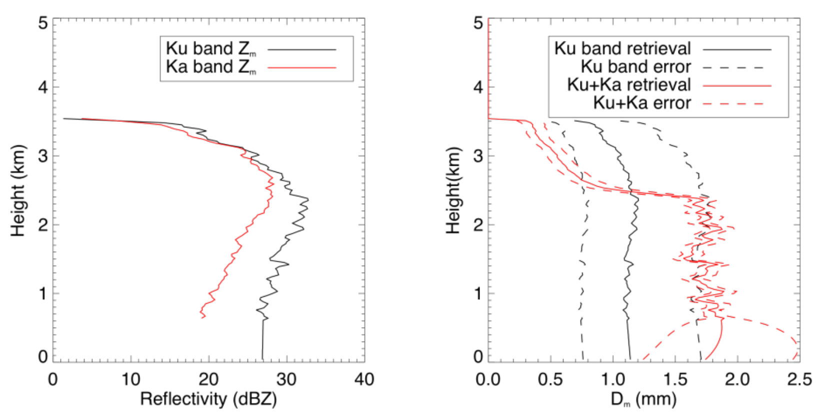


Figure 2: Retrieval of mean raindrop size from a warm rain cell. Data from the APR2 instrument on board the NASA DC-8 during the Genesis and Rapid Intensification Project (GRIP). Note that errors for the dual-frequency retrieval (GPM) are much smaller than the single-frequency retrieval (TRMM).

Name: S. Joseph Munchak, NASA/GSFC, Code 612 and University of Maryland/ESSIC
E-mail: s.j.munchak@nasa.gov
Phone: 301-286-2392

References:
Munchak, S. J., C. Kummerow, and G. Elsaesser, 2011: Relationships between the Raindrop Size Distribution and Properties of the Environment and Clouds Inferred from TRMM. *Journal of Climate*, accepted.

Munchak, S. J. and C. Kummerow, 2011: A Modular Optimal Estimation Method for Combined Radar-Radiometer Precipitation Profiling. *Journal of Applied Meteorology and Climatology*, **50**, 223-239.

Grecu, M., L. Tian, W. S. Olson, S. Tanelli, 2011: A Robust Dual-Frequency Radar Profiling Algorithm. *Journal of Applied Meteorology and Climatology*, **50**, 1543-1557.

Data Sources: TRMM PR, TMI, VIRS, and LIS, MERRA (Figure 1), APR2 on NASA DC-8 (Figure 2)

Technical Description of Figures:
Figure 1: The top panel shows the gridded mean value of median raindrop diameter D_0 normalized by radar reflectivity Z. This parameter is retrieved for each precipitation profile observed by the TRMM PR for two years (June 1999-May 2000 and January-December 2006) selected to represent pre- and post-orbit-boost periods. The bottom panel shows the value of this same parameter predicted by the first three principle components of relationships derived from these retrievals and parameters representing the environment (freezing level height, lapse rate, relative humidity; from MERRA), mesoscale organization (number and echo top height of PR profiles within 100 km), and vertical profile (echo top height, bright band strength, slope of reflectivity in the rain layer; from PR).

Figure 2: The left panel shows Ku- and Ka-band reflectivity profiles of a warm rain cell measured by the APR2 instrument during the GRIP field experiment in 2010. The right panel shows profiles of retrieved raindrop mean mass diameter (D_m), which is closely related to D_0. The retrievals follow the technique developed by Grecu et. (2011). This algorithm was specifically designed for use of Ku-band radar both with and without corresponding Ka-band data to accommodate the anticipated scan strategy of GPM, which will have an inner dual-frequency swath nested in a larger single-frequency swath. Error bars representing one standard deviation are presented for each retrieval based on optimal estimation theory.

Scientific significance: Knowledge of the global patterns of the raindrop size distribution (DSD) is particularly useful for radar-based rainfall retrievals and to a lesser, but still significant extent for passive microwave radiometer-based retrievals. To put the variations shown in Figure 1 in perspective, a 25% change in the value of D_0 is equivalent to a 90% change in rainfall rate at a given reflectivity. Therefore knowledge of the DSD climatology and the ability to predict DSD from other observable parameters has the potential to improve radar-based rainfall estimates on a variety of scales. These results are also significant to aiding our understanding of rainfall microphysical processes and how these vary over the globe.

Relevance for future science and relationship to Decadal Survey: This research will be greatly enhanced by the data from GPM, as shown by the much smaller error in raindrop size retrieval with a dual-frequency precipitation radar. In addition to providing better instantaneous measurements, these data will be able to identify any long-term biases in the TRMM-based climatology presented in Figure 1, especially if there is an overlap period in the operations of these two satellites.

More tornados and hailstorms observed in the middle of the week

Daniel Rosenfeld and Thomas L. Bell

Hailstorm and tornado activity increases in the middle of the work week (Tuesday-Thursday) compared to weekends, as shown in a recently published paper[1] by Rosenfeld and Bell in the Journal of Geophysical Research. Weekly cycles in weather behavior are a clear sign of human influence on our climate.

The weekly cycle is believed[2] to be caused by the well-known weekly changes in pollution levels with the day of the week. Aerosol pollution decreases the size of water droplets coalescing in clouds. They are lighter and don't fall out as rain, but instead rise to much higher altitudes where they freeze and release additional heat ("latent heat of fusion"). This invigorates the storm and produces more ice aloft. This might explain the increase in hailstorms as well as the increase in lightning that has also been observed.[3] It is conjectured by Rosenfeld and Bell (2011), based on numerical model simulations, that storms, amped up by pollution, nevertheless produce weaker cold pools at their base. Tornados develop less easily when a cold, rapidly moving pool forms beneath the storm. By weakening cold pool formation, pollution may lead to storms with better chances of forming a tornado than is the case for storms formed in clean air.

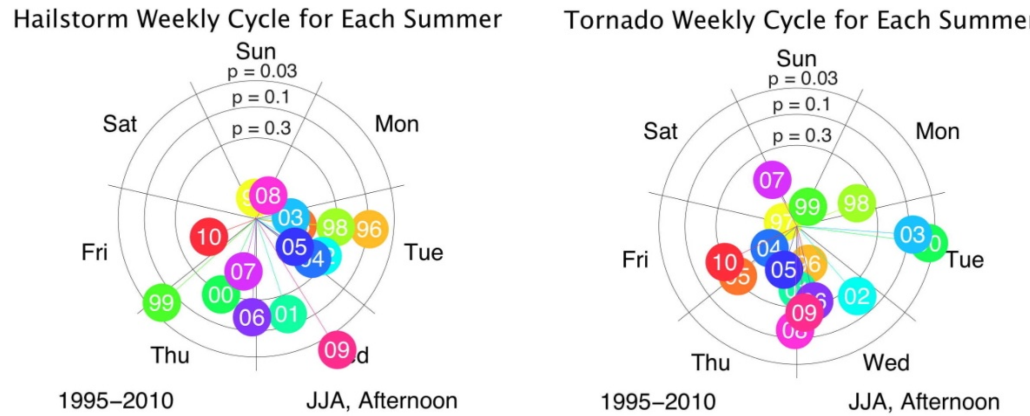


Figure 1: Each colored balloon with the last two digits of the year inscribed shows the day of the week favored by storms for a given summer (Jun–Aug). The balloon's distance from the origin shows the "strength" of the cycle: a balloon close to the origin means that the cycle was very noisy and the favored day of the week difficult to determine.

The Figure shows statistics for the year 2010 added to the years 1995–2009 analyzed in the paper by Rosenfeld and Bell (2011). The weekly cycle detected for the summer of 2010 was weak. The day of the week with maximum activity for 2010, Friday, again falls outside the weekend sector. Since each summer supplies only 13 weeks of data (i.e., 13 "experiments"), and hailstorm and tornado occurrences are quite sporadic, statistical results for a single summer are themselves bound to be noisy. Although the balloons obviously tend to avoid the "weekends" (Sat-Mon), those that fall in the weekend sector also tend to cluster near the origin, indicating that the data are not very conclusive about the day of the week in those cases.

Since 10% fluctuations in aerosol pollution relative to background levels may be producing 10% fluctuations in severe storm activity (not shown here), this suggests that the "background" anthropogenic aerosol levels may be making storms more severe than what we would be experiencing in a cleaner atmosphere.

Name: Thomas L. Bell, Code 613, Emeritus
E-mail: Thomas.L.Bell@nasa.gov
Phone: 301-614-6197

Daniel Rosenfeld, The Hebrew University of Jerusalem
Email: daniel.rosenfeld@huji.ac.il

References:

1.Rosenfeld, D., and T. L. Bell (2011): Why do tornados and hailstorms rest on weekends? *Journal of Geophysical Research*, **116**, D20211, doi: 10.1029/2011JD016214.

2.Bell, T. L., D. Rosenfeld, K.-M. Kim, J.-M. Yoo, M.-I. Lee, and M. Hahnenberger (2008): Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms, *Journal of Geophysical Research*, **113**, D02209, doi:10.1029/2007JD008623.

3.Bell, T. L., D. Rosenfeld, and K.-M. Kim (2009): Weekly cycle of lightning: Evidence of storm invigoration by pollution. *Geophysical Research Letters*, **36**, L23805, doi:10.1029/2009GL040915.

Data Sources: Data were collected by NOAA's Storm Prediction Center [*SPC]*, in the form of lists of locations, times, and strengths of tornados or hailstorms, available from the web site http://www.spc.noaa.gov/wcm/index.html#data.

Technical Description of Figures:

Figure 1: Summertime occurrences of storms over the U.S. east of longitude 100W were counted for each day of a summer (Jun-Aug, 92 days). The mean rate of occurrence for each day of the week was fit to a 7-day sinusoidal curve, and a "balloon" is placed on the clock plot in the sector corresponding to the day when the sinusoidal fit peaks. The statistical confidence in the fit is estimated from the quality of the fit and a "signal-to-noise" ratio for the fit used to determine the radial location of the balloon. The "p-values" labeling the circles indicate the probabilities that data consisting of pure noise (unpredictable weather variations) could accidentally produce sinusoids with signal-to-noise values outside the given circle. Note that a single summer of data, 13 weeks, has relatively few "samples". Statistics derived from so few samples are correspondingly noisy. There are about 7 times as many recorded hailstorms as tornados, and the clock plot for hailstorms presents us with a clearer picture than for tornados.

Scientific significance: This study reinforces and extends the conclusions reached in earlier studies using TRMM data that showed that both rainfall area and rain intensity increase in the middle of the week over the SE U.S. during the summertime. The changes, when averaged over 15 years of data, are highly significant statistically. If the theory behind the changes seen in the averages are correct, human pollution can change weather in profound ways that are entirely distinct from the much-discussed issues related to "greenhouse warming". Human pollution can shift rain patterns and cause increases in tornado and hailstorm frequency in areas susceptible to the influence of aerosols (identified in the theory as areas both with high humidity and unstable to the formation of intense storms, and where cloud bases are well below the freezing level of the atmosphere, as occurs over the eastern U.S. during the summer). Humans are, in effect, changing the climate back and forth every week, by shifting aerosol pollution levels above and below the background average each week. This causes one to ask, "How has the background level of aerosols itself changed the weather we experience?"

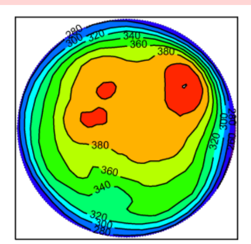
Current weather forecast models do not include the effects of changing aerosol pollution, partly because it is not well observed. Weather forecasts are therefore not yet capable of warning us of changes in storm intensities caused by different pollution levels.

Relevance for future science and relationship to Decadal Survey: This research is highly relevant to several of the challenges contained in the Decadal Survey: climate changes as reflected in changes in severe storm behavior and in shifts of rainfall patterns, and weather forecasting. It underlines the need for monitoring aerosol concentrations in the atmosphere on a continuing basis.

What caused unusually low Arctic O_3 in Spring 2011?

The Microwave Limb Sounder (MLS) on NASA's Aura shows weaker than usual ozone transport and strong photochemical loss

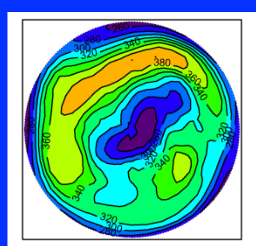
MLS Late March Arctic O_3 (DU)



The MLS 2005-2010 average shows stratospheric columns are ~390 Dobson Units (DU).

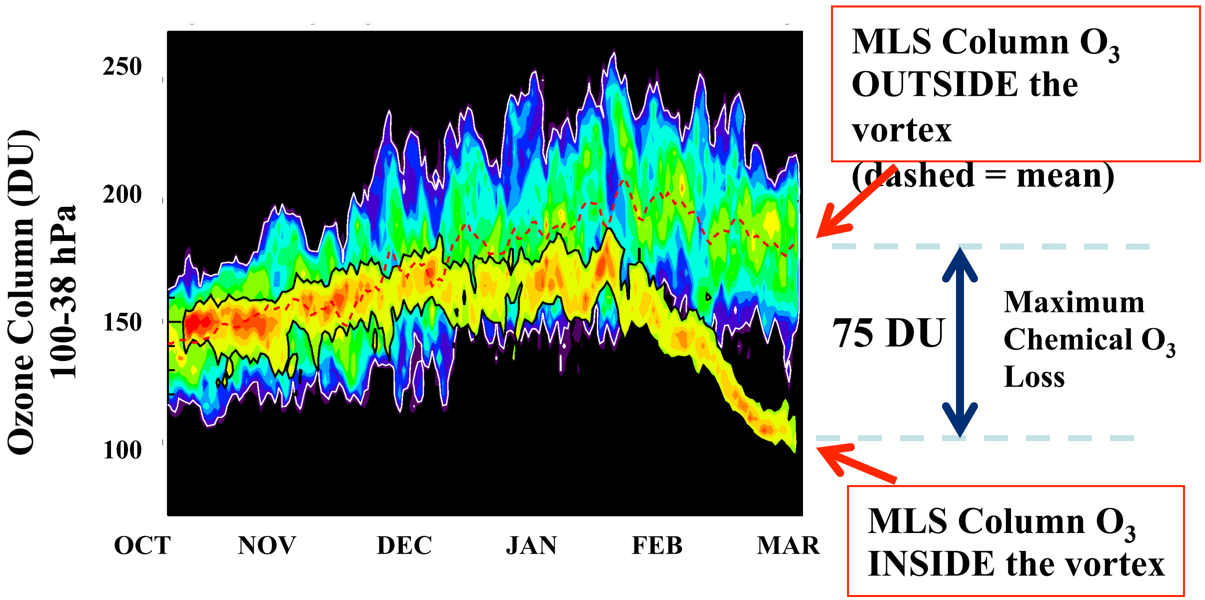
Why? The vortex has broken down, allowing high O_3 to be transported to high latitudes.

2011: MLS O3 columns are less than 260 DU at high latitudes!



Why? The 2011 vortex persists through late March, prohibiting the transport of O_3 rich air from lower latitudes. Low temperatures also cause significant chemical loss.

2011 Arctic Ozone



The difference between the means *inside* and *outside* the lower stratospheric vortex is an estimate of chemical O_3 loss. *Vortex chemical loss is at most 75 DU.*

Weaker than usual transport to high latitudes leads to ozone stratospheric columns <u>*outside the vortex*</u> ~25 DU lower than 2005-2010 average.

S.E. Strahan, Code 614, manuscript in preparation.

Susan E. Strahan, GESTAR, NASA/GSFC, Code 614
E-mail: susan.strahan@nasa.gov
Phone: 301-614-5995

Data Sources: Microwave Limb Sounder (MLS) ozone (O_3) and temperature data, version 3.3. GMAO Modern Era Retrospective-Analysis for Research and Applications (MERRA) potential vorticity product.

Technical Description of Figures:
Figures on Left Side: MLS has measured stratospheric ozone since 2004.These figures show the stratospheric columns (measured in Dobson Units, DU) for late March averaged of 6-yrs, 2005-2010 (upper panel). Arctic mean stratospheric columns poleward of 54^{o}N averaged 390 DU but in March 2011 the same area averaged less than 340 DU, with some areas as low as 240 DU (lower panel).

Figure on Right Side: Contours of area-weighted probability distributions functions (PDFs) for MLS partial column O_3 from Oct 1, 2010-Mar 26, 2010. The partial column is calculated from O_3 data from the 100-38 hPa pressure levels and represents the altitude range over which chlorine-catalyzed O_3 loss takes place. The wider contours, in blues and greens, show the distribution of the partial columns outside the Arctic vortex while the narrower contours, in yellows and reds, shows the distributions inside the isolated vortex. Chemical O_3 loss occurs only inside the vortex. The difference between the means of these two distributions provides an estimate of the maximum amount of chemical O_3 loss that has taken place.

Scientific significance: Every year, Arctic column O_3 has a significant increase during fall and winter due to transport from lower latitudes. Polar stratospheric clouds (PSCs) form inside the Arctic vortex if temperatures are low enough and cause O_3 loss in winter. The polar vortex forms during fall, isolating a large, high latitude air mass from the effects of horizontal transport. Most years the vortex has broken down by late March; vortex breakdown leads to warm temperatures and a resurgence of high O_3. In 2011 the vortex was strong and long-lasting, and the usual seasonal transport of ozone-rich air to polar latitudes did not occur until April. This atypical stratospheric meteorology explains part of the low ozone columns observed in late March by MLS and the Ozone Measuring Instrument (OMI) on Aura.

Low temperatures in the Arctic vortex in February and March 2011 caused PSC-catalyzed ozone loss. By differencing the partial columns outside and inside the LS vortex we get an upper limit on chemical ozone loss inside the vortex. It is an upper limit because there will be slightly more transport of O_3 outside the vortex than inside. By comparing the 2011 partial columns above and below the LS with those columns from previous years (not shown), we see that ozone in vortex regions unaffected by PSCs (i.e., O_3 loss)was also lower in 2011.

Relevance for future science and Decadal Survey Missions: It is important for us to distinguish between low polar O_3 caused by PSC-catalyzed loss and low O_3 resulting from interannual variability in stratospheric meteorology. Stratospheric Cl is expected to decline in this century due to decreases in the emissions of Cl-containing, long-lived halocarbon gases. However, stratospheric temperatures and circulation are also expected to change due to increasing abundances of greenhouse gases. We need to be able to correctly attribute changes in polar O_3 to the effects of decreasing atmospheric Cl and to the effects of climate change on stratospheric circulation. Measurements from GACM will determine additional instances of Arctic ozone depletion and its relationship to meteorology.